the Energy to Lead

# CARB Project Seminar ICAT #04-1
# Field Demonstration of Prototype Super Boiler

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gti

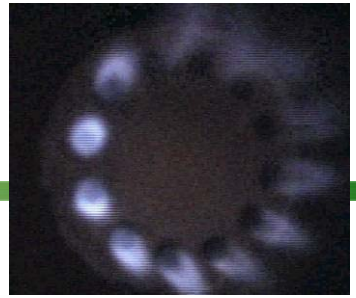
# Super Boiler Background

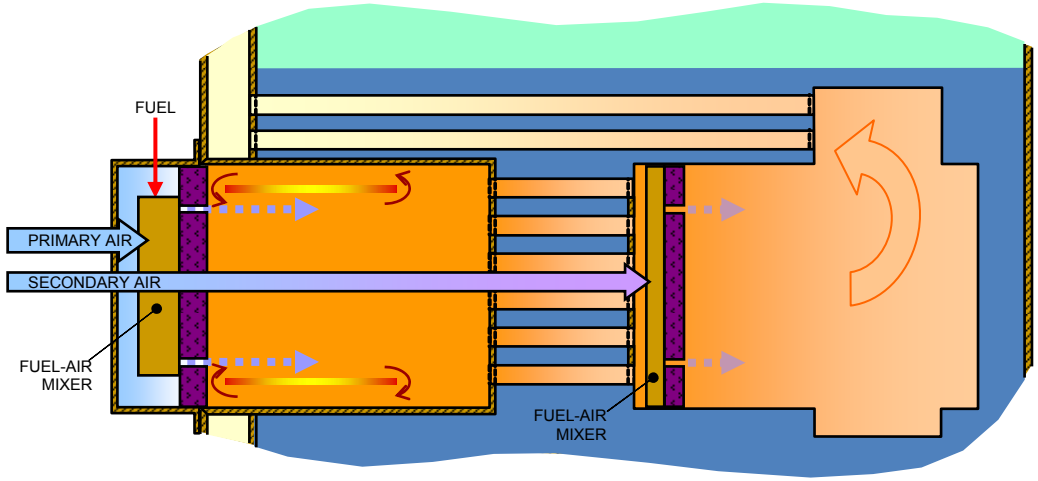
- U.S. industrial and commercial steam boilers
  - Consume over 6 quads of natural gas per year
  - Wide range of steam uses from process steam to space heating
- Installed base of steam boilers
  - Largely over 30 years old
  - Average efficiency 76%
  - Typical NOx emissions 85 ppmv
  - Significant potential for improved technology

# Project Origin & Goals

- Super Boiler program
  - Started by DOE and gas industry in 1999
  - GTI team with Cleaver-Brooks selected for project
- Goals:
  - Maximum efficiency (94 to 95 %)
  - NOx and CO less than 5 ppmv
  - Reduced footprint and weight
  - Cost-effectiveness
- ICAT Project (Started in July 2005)
  - Select Host Site, Design & Fabricate, Install & Test Two Stage Firetube Super Boiler with TMC HRS

# Combustion: two-stage*






- 80 HP lab boiler
  - Staged burner with internal recirculation
  - Interstage cooling pass
  - No FGR required
  - 3-5 ppmv NOx at 1-2% $O_2$



* U.S. Patent No. 6,289,851 (Sept 2001), U.S. Patent No. 6,971,336 B1 (Dec. 2005)

# Combustion: two-stage field demo

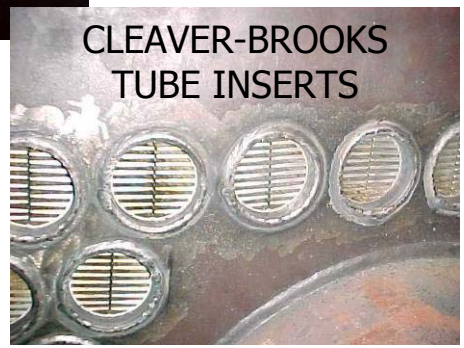
- 300 HP field demonstration
  - Clement Pappas & Co. (Ontario CA)
  - Juice and beverage bottler
  - Steam used for pasteur-ization and cleaning
  - Steam demand = zero to 9,500 lb/h, highly variable
  - Scale-up included integral head design
  - Operates year-round 24/7
  - Started testing Feb 2008

# Combustion: two-stage controls

- Operator interface via Hawk ICS touchscreen PLC control panel
- PLC control
  - Critical first stage fuel/air ratio control via fuel delta-P and windbox air delta-P
  - Control implemented via parallel positioning (PP) controllers with VFD trim
  - $O_2$ trim integrated into air split management
  - Separate setups for heat recovery and bypass modes

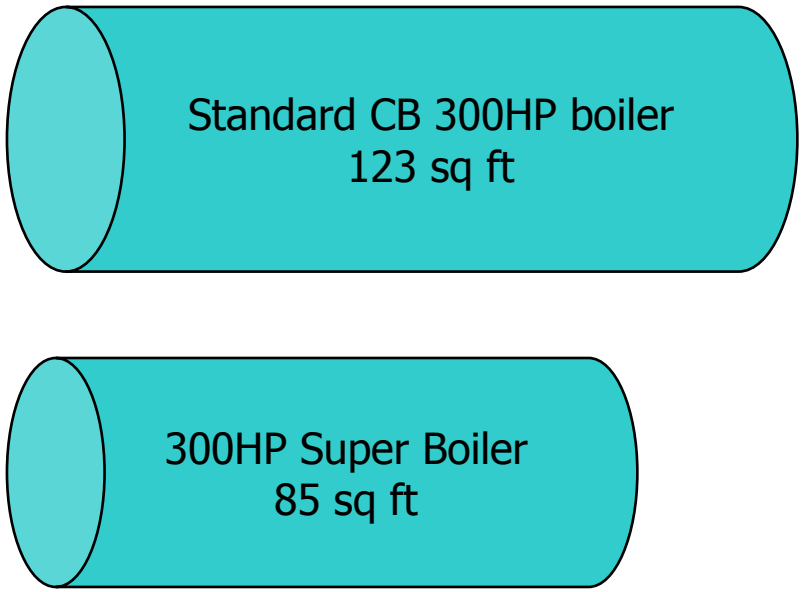
# Heat Transfer: convective pass

- Enhanced firetube heat transfer
  - Fire-tubes with extruded aluminum inserts
  - Heat transfer 18X higher than conventional tubes
  - 2-pass boiler can deliver 4-pass performance with a smaller footprint


# Heat Transfer: field demonstration

- 300 HP field demonstration
  - CA demo uses finned firetube inserts in two-pass design
  - Flue gas cooled to 35°F above steam temperature
  - California Super Boiler: 38% lighter & 31% smaller footprint than conventional 300 HP boiler

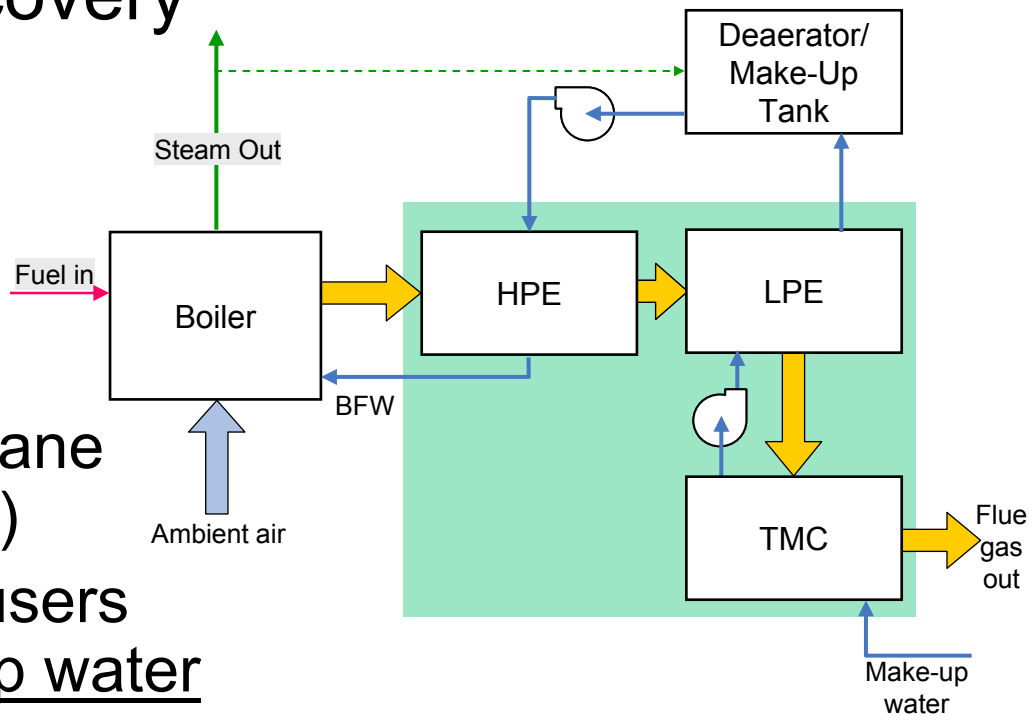


# HEAT RECOVERY

- Natural gas combustion produces about 18% water from oxidation of H in fuel
- Water vapor up the stack accounts for 10% of fuel energy input, or 65% of stack loss
- Key to higher energy efficiency is to recover both sensible *and* latent heat

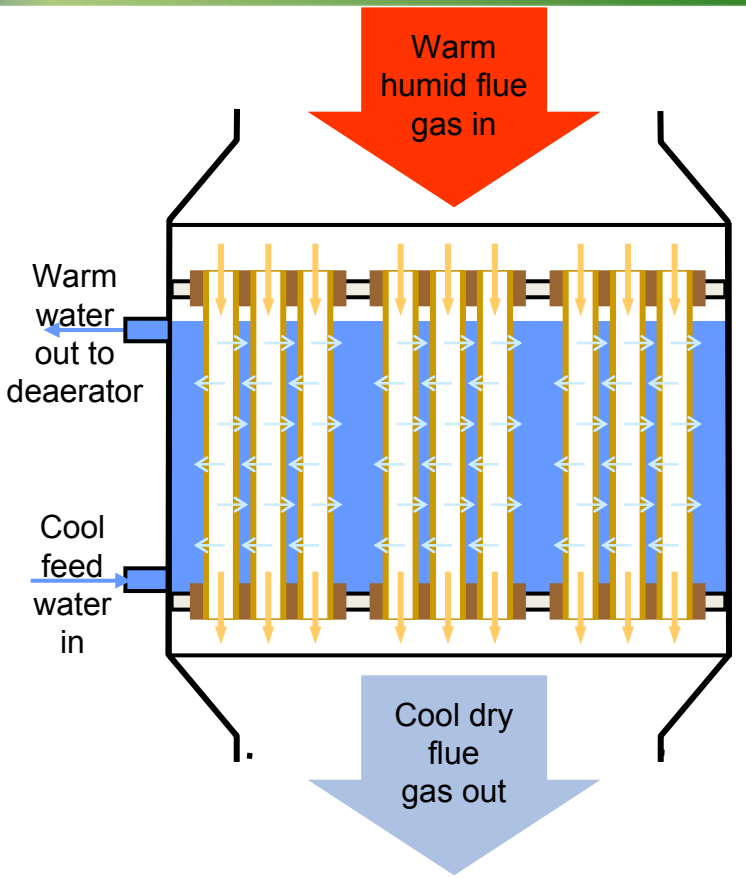
# Heat Recovery: general approach

- Flue gas heat recovery
  - Remove sensible heat with two economizers
  - Remove latent heat with Transport Membrane Condenser (TMC)
  - Suitable for end users with high make-up water usage



# Heat Recovery: TMC concept*

- Transport Membrane Condenser (TMC)
  - Nanoporous ceramic membrane tubes
  - Water vapor permeation via capillary condensation
  - Partial vacuum on shell side
  - Counter-flow configuration

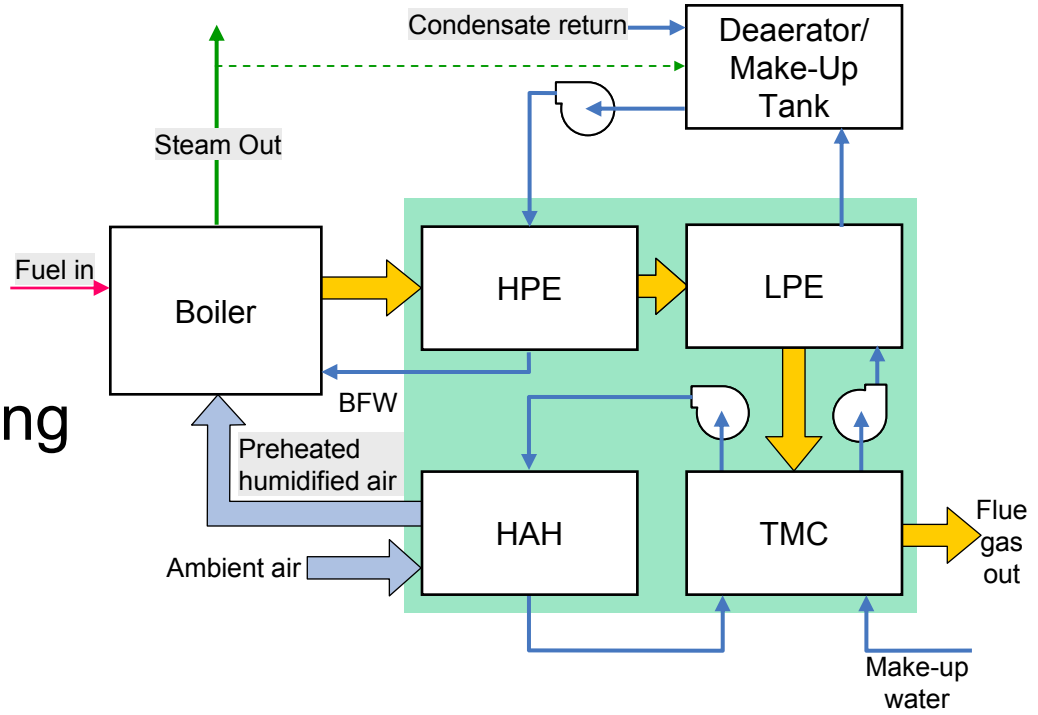





* U.S. Patent No. 6,517,607, 2008 Chicago Innovation Award

# Heat Recovery: expanded system*

- Applications with high condensate return
  - Limited make-up water reduces TMC capacity
  - Recycle water through humidifying air heater (HAH)






*U.S. Patent No. 7,066,396

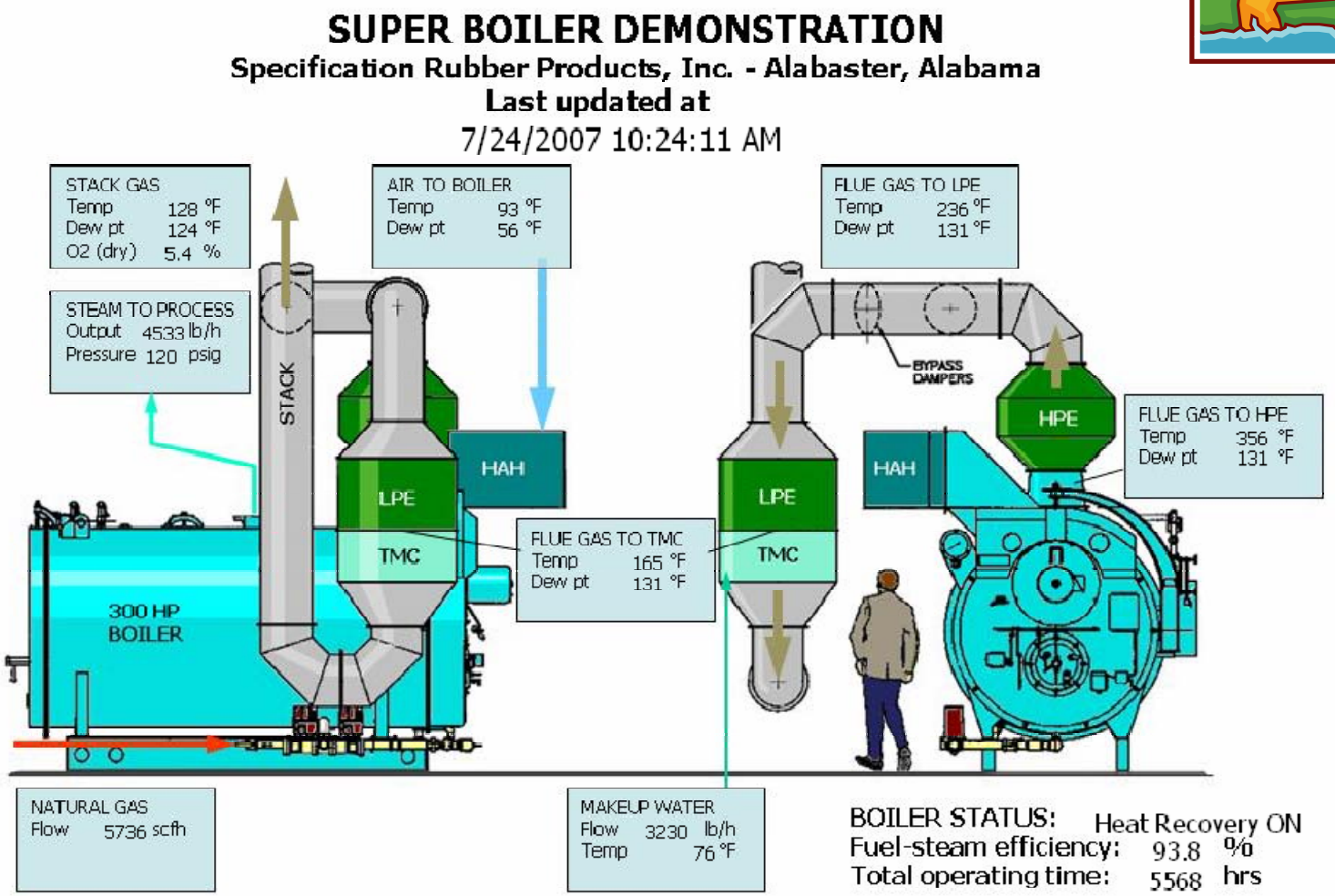
# Heat Recovery: TMC hardware

- Down-flow “Version 1.0”
  - Cylindrical shell design
  - Tube bundles (17” x 4”), 99 tubes/bundle
  - Water on shell side with bottom inlet for natural counter-flow
  - Flue gas cooled to <160°F
  - Shell-side vacuum 3 psid
  - Flue gas pressure drop <4 in WC


TMC (3 MMBtu/h)

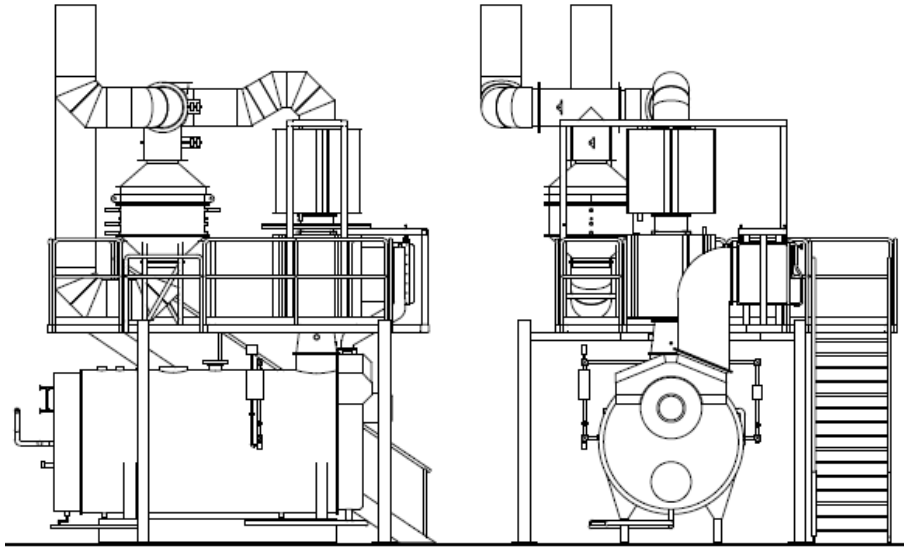

TMC

# Heat Recovery: Alabama field demo

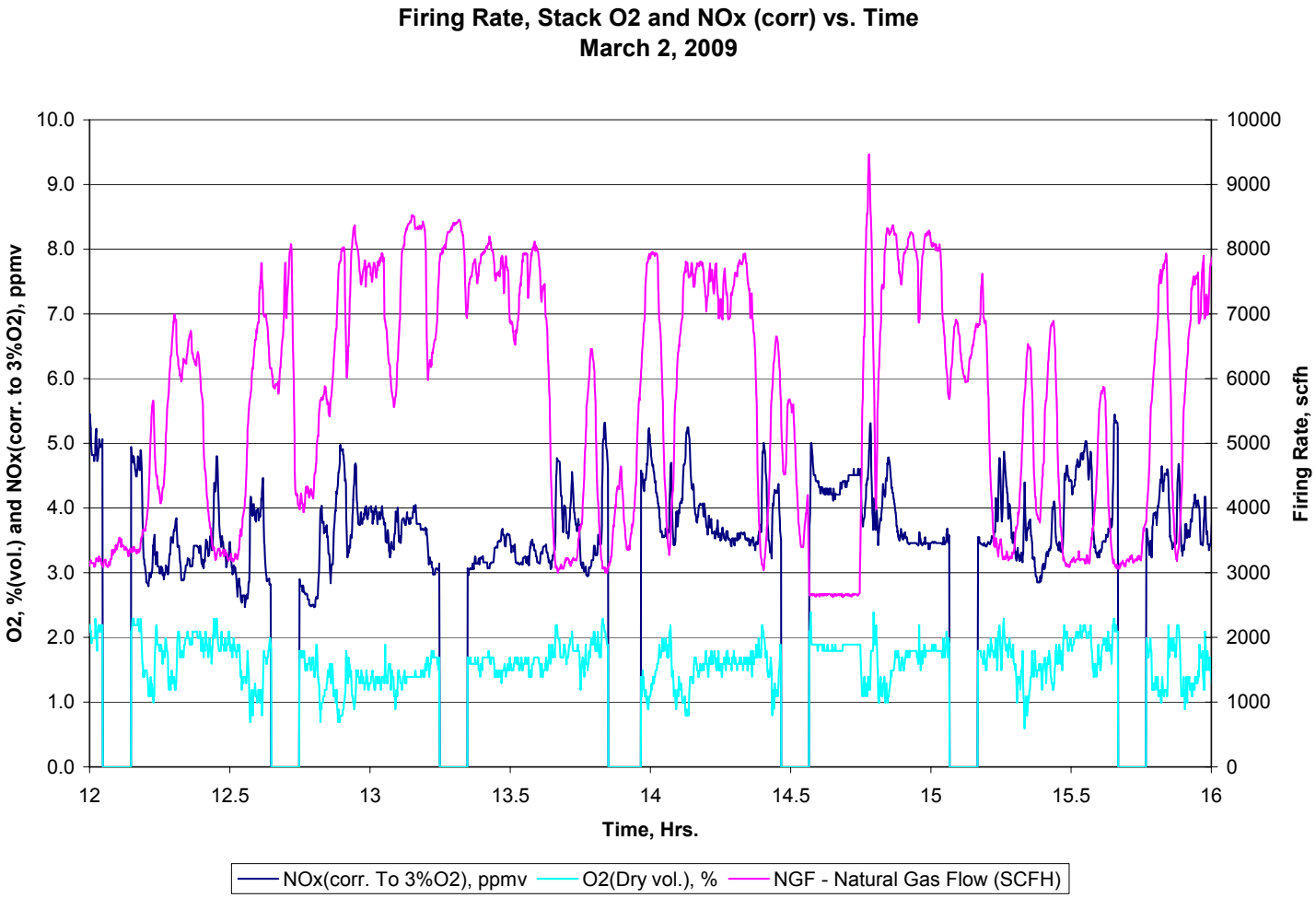


# Heat Recovery: California field demo

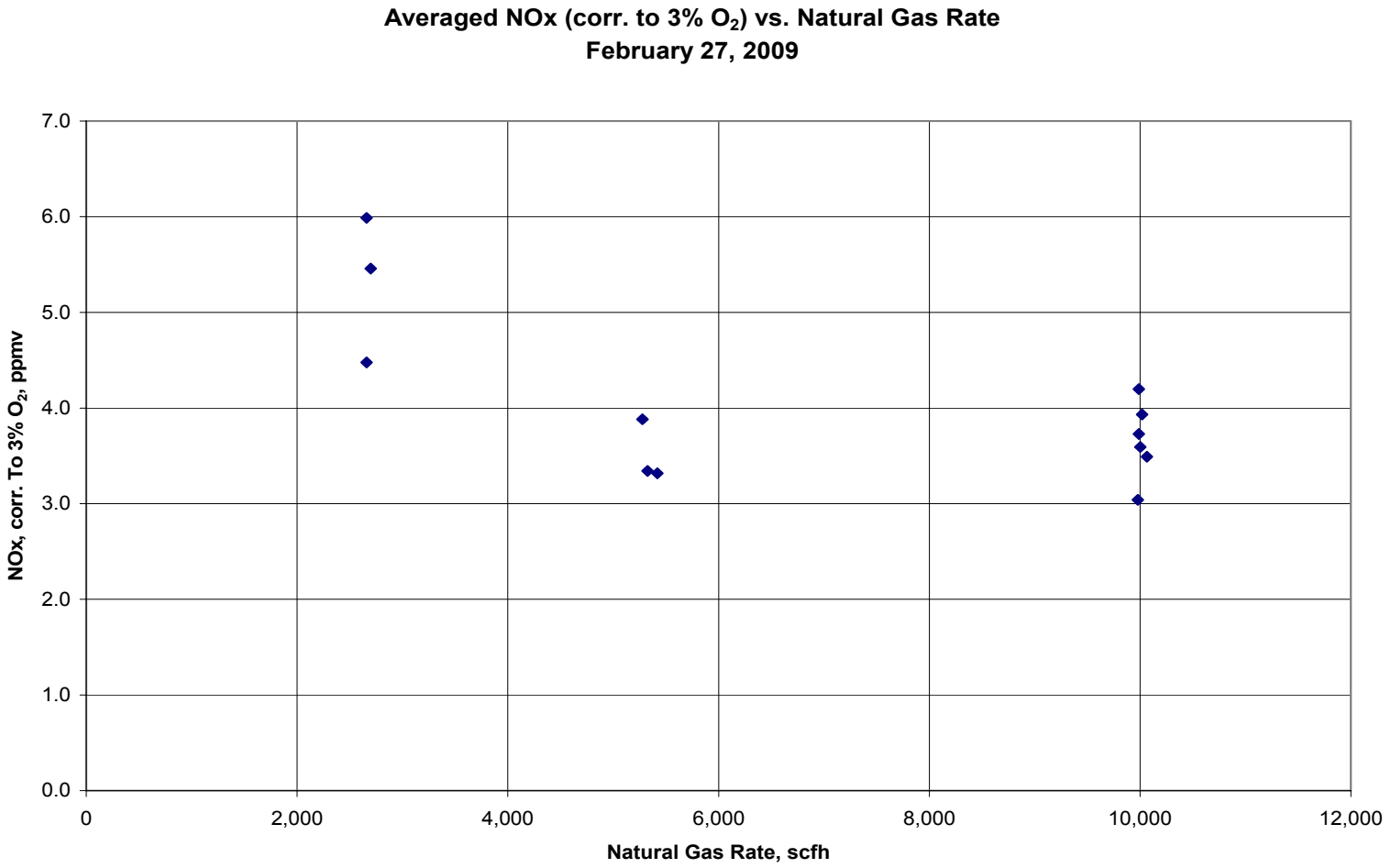
- Clement Pappas & Co. in Ontario CA
  - Heat recovery system (HRS) similar to Alabama site
  - HRS mounted above boiler



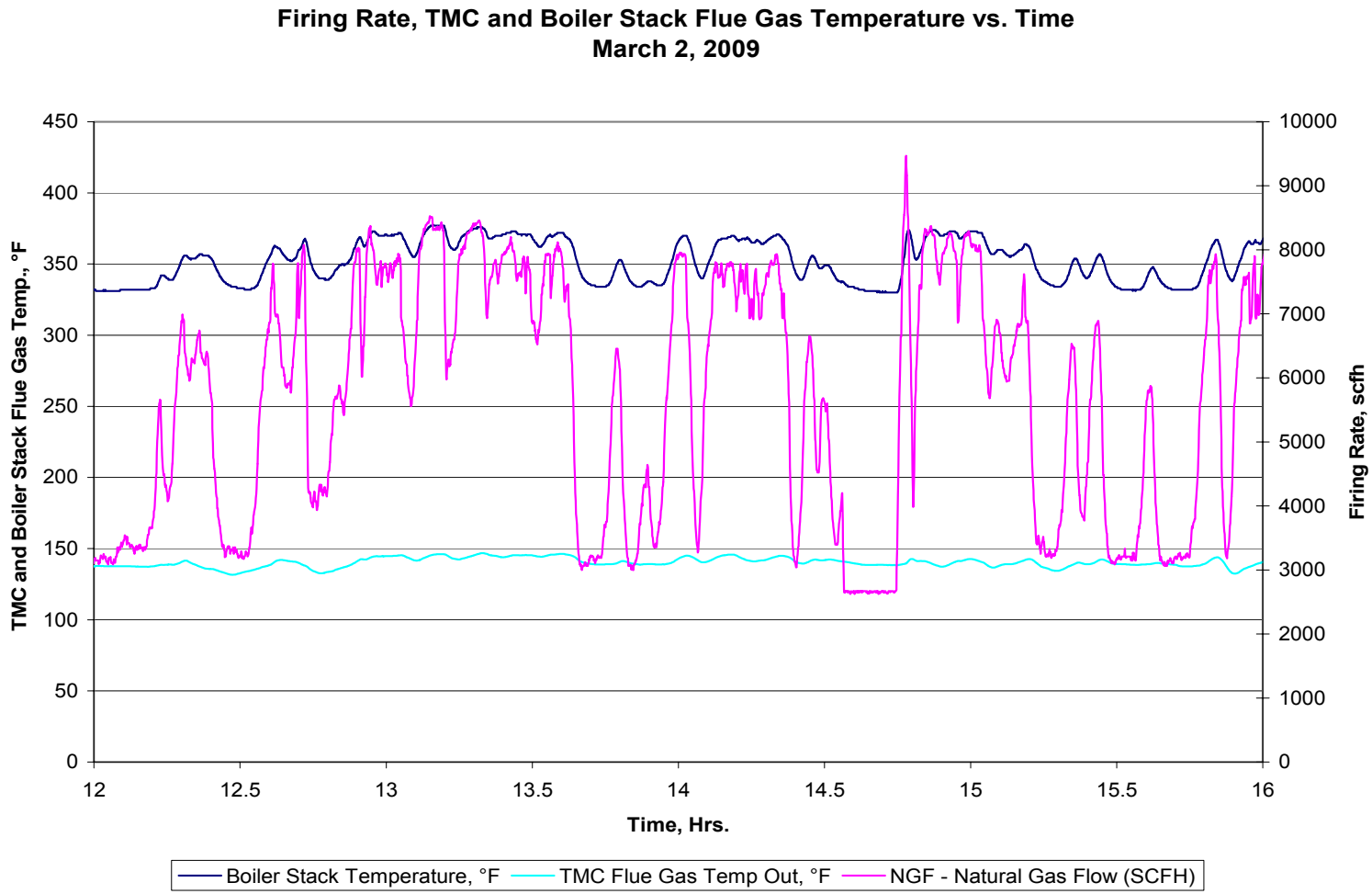
# 300 hp Super Boiler Clement Pappas Continuous Emission Results



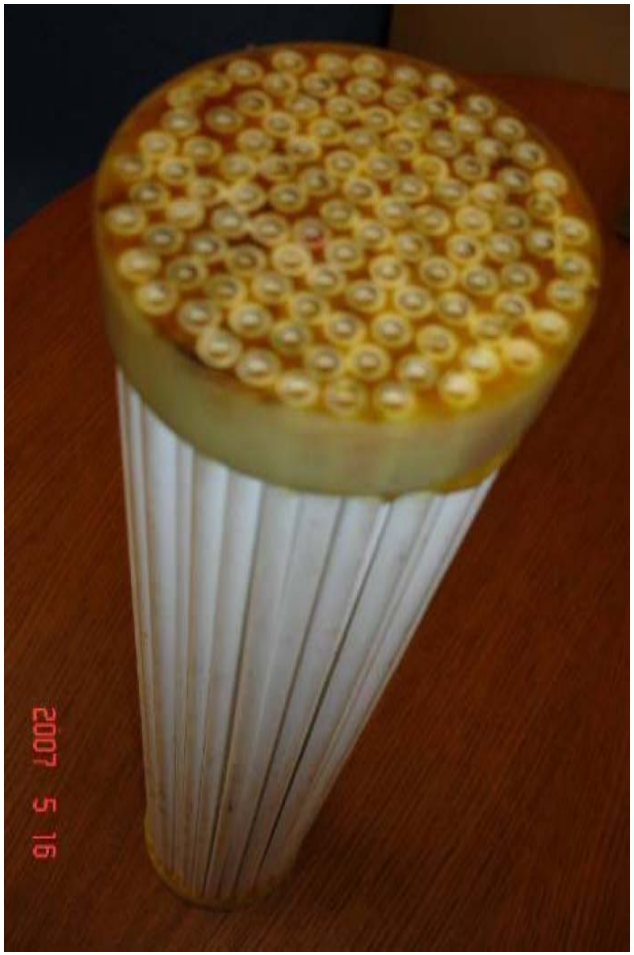
# 300 hp Super Boiler NOx Emissions as a function of Firing Rate



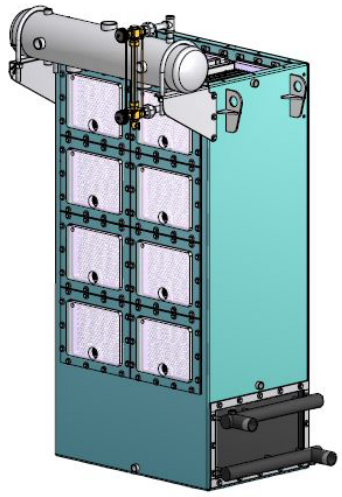
# 300 hp Super Boiler CP TMC Heat Recovery Results



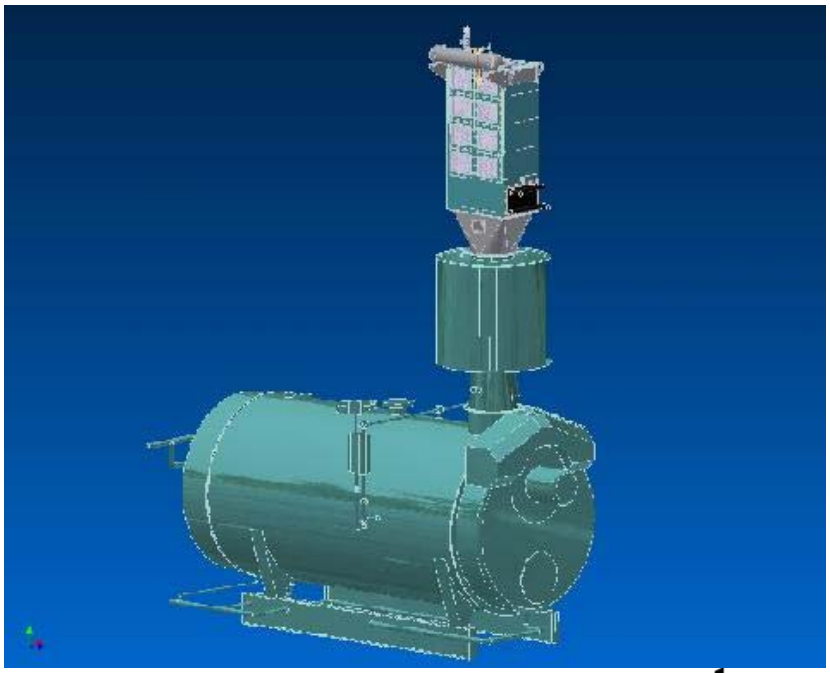
# 1st and 2nd Generation Membrane Bundles




# Heat Recovery: improved TMC design

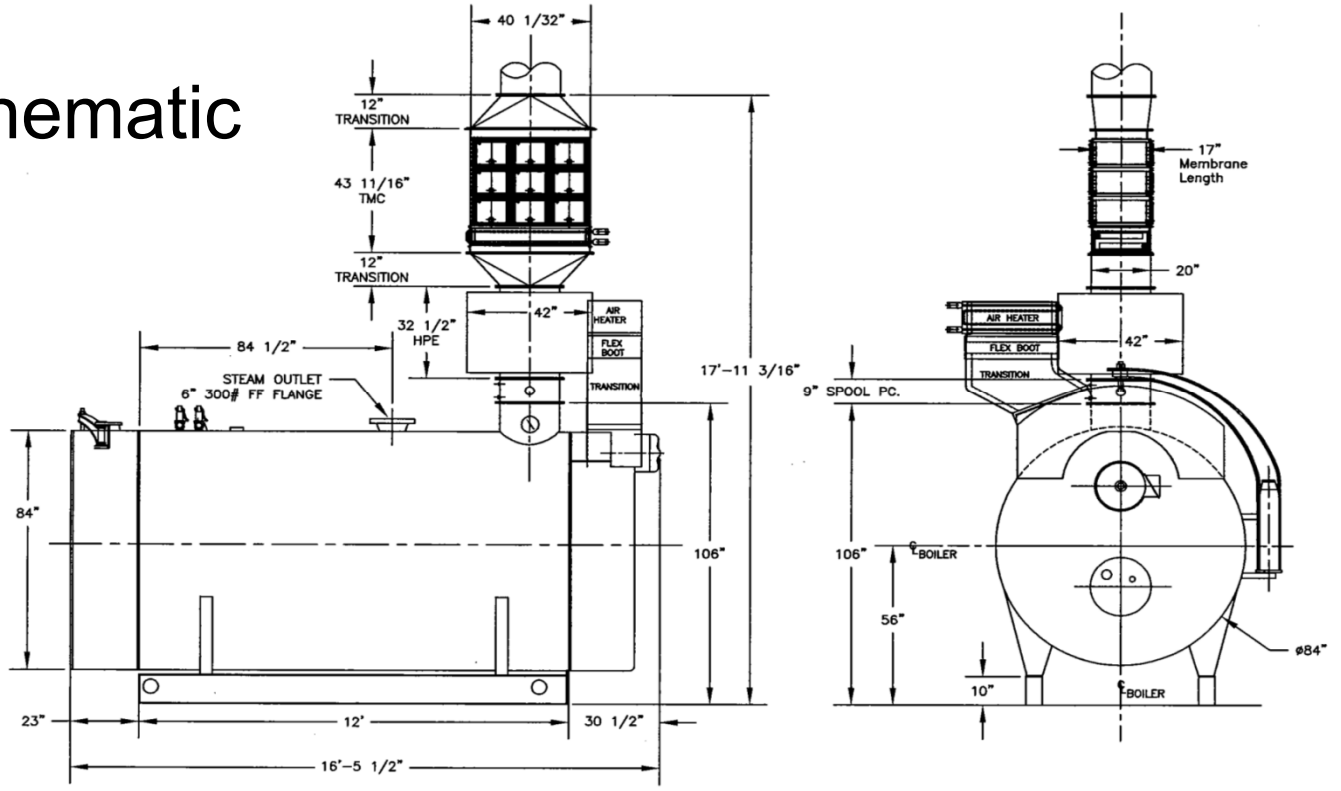


- Up flow “Version 2.0”
  - Modular design
  - 25-HP tube bundle modules
  - Water inside tubes with staged downward flow
  - Above-boiler mounting
  - Easier assembly and service
  - More compact
  - Less ductwork



# Proposed Heat Recovery Retrofit for 250 hp 150 psig CB Boiler

> Schematic



# Evaluation of TMC HRS Retrofit to 250 hp Boiler

## Present Boiler

- Fuel: 902,000 therms/yr.
- Water: 2,000,000 gallons/yr
- Stack Temperature: 407 F
- Efficiency: 82 %

## Retrofit with TMC HRS

- Fuel: 786,500 therms/yr
- Water: 1,600,000 gallons/yr
- Stack Temperature: 130 F
- Efficiency: 94 %
- Savings: 115,500 therms/yr
- Fuel Savings: $138,600/yr based on $1.20/therm
- Water Savings: $11,700/yr based on $2.20/750 gal's

# Thanks to the Sponsors of the 300 hp Super Boiler Technology and Field Demo

- California Air Resource Board
- U.S. Dept of Energy
- Southern California Gas Company
- GTI Sustaining Membership Program
- Clement Pappas
- Gas Research Institute
- Cleaver-Brooks
- California Energy Com
- Utilization Technology Development Co.
- South Coast Air Quality Management District